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MAGNETO-OPTIC EFFECTS @ 1.15 MICROMETER IN $Gd_{.5}Y_{2.5}Ga_1$ IRON GARNET THIN FILM WAVEGUIDES

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13 ABSTRACT

We have built an experimental setup which enables us to view the magnetic domains in the film and measure the conversion efficiency simultaneously. Reasonable mode conversion efficiency is obtained, only when the stripe magnetic domains in the film are eliminated along the line of light propagation. The bias field (H_a) required to annihilate the stripe domain is dependent on the direction of the bias field with respect to the axes of magnetic anisotropy. The annihilation field (H_a) is found to be maxima, of the order of 50 Oe, at 0, ±60, ±120 degrees from the easy axis, and minima of the order of 2 Oe at ±45 degrees from the hard axis. Our finding has not only given us a better understanding of the conversion phenomenon, but also provided us with a means of selecting the proper direction of the bias field so that the power consumed would be minimal in our subsequent application of the device as switches or modulators.

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Magnetic domains						

MAGNETO-OPTIC EFFECTS @ 1.15 μm in $Gd_{.5}Y_{2.5}Ga_{1}$
IRON GARNET THIN FILM WAVEGUIDES

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by

A. R. Reisinger
S. C. Tseng (principal investigator)

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TABLE OF CONTENTS

I. INTRODUCTION

As described in our previous report, we have achieved high efficiency (30%) TE $\rightleftarrows$ TM mode conversion of optical guided waves in magnetic garnet films subjected to the proximity fields of a periodic permalloy structure[1]. Theoretically, it is known that the mode conversion is contributed only by a longitudinal field via Faraday rotation. Nevertheless, the experiment shows that a transverse bias field, in addition to the longitudinal field, is required in order to obtain an optimum efficiency. This finding has prompted us to investigate the effect of magnetic anisotropy and magnetic domain structures of the film on the mode conversion efficiency. We consider such information useful in the selection of the proper direction for bias magnetic field, so that the power required for a given index of modulation would be minimum in our subsequent applications of the waveguide. For modulation or switching application of magneto-optical waveguides, it is desirable that the film be magnetized into a single magnetic domain and that the modulation be induced by uniform rotation of magnetization, rather than by wall motion since magnetization rotation is known to be fast enough for nanosecond rise time switching[2] while domain wall motion in a multi domain film responds slowly to the modulating signal. In order to turn the film into a single domain, a magnetic bias field can be applied. However, if the bias field required for single domain is too large compared to the modulating field, the magnetization will not be perturbed considerably from its equilibrium position, which is determined by the strength of the bias.

This will result in a small index of modulation. One can, of course, increase the modulating field, but then the modulating power increases. In view of the above, a low power, large bandwidth device can be made only with magnetic garnet films which require the lowest possible magnetic field for saturation. We have conducted the following investigation, aiming at collecting experimental data for the future assessment of the magneto-optical waveguides as modulators.

II. B-H CURVES

All the films $(Y_{2.5}Gd_{.5})(Fe_4Ga)O_{12}$ which are epitaxially grown on (111) plane of GGG substrates show a preferred easy axis and a hard axis, in their B-H curves (Fig. 1a,b) when they are subjected to a 60 Hz in-plane magnetic field. X-ray analysis indicates that the easy axis is along the [110] direction and the hard axis along the [211] direction. The upper traces are the B-H curves, when the in-plane field is applied along the easy axis. It appears that the horizontal component of the magnetization is saturated in a field as low as 0.5 Oe. The lower traces are the B-H curves taken along the hard axis. It appears that the horizontal component of the magnetization reaches partial saturation at 0.5 Oe and shows magnetization rotation at 3 Oe. At about 6 Oe, the horizontal component of the magnetization reaches saturation along the hard axis. From this measurement alone, one would be tempted to conclude that the bias should be applied along the easy axis. We, however, realized that the B-H curve reveals only the property of the horizontal component of the magnetization. Whether the film is a

single domain or not, the vertical component of the magnetization has to be investigated also.

III. STRIPE DOMAIN

Normal components of the domain structures are investigated by passing normally incident light through the magneto-optical film which is sandwiched between a polarizer and an analyzer. Upon application of an in-plane magnetic field, stripe domains such as those in Fig. 2a,b,c are observed. When the magnetic field is along the easy axis, the stripes are perpendicular to the magnetic field. The period of the domain, however, decreases to a finer structure as the magnetic field increases. At strong field (60 Oe) the domain structure vanishes and the film becomes a uniform domain. Along the hard axis, the stripes are again perpendicular to the magnetic field first at low field intensity (8 Oe). As the field is increased to a certain value (16 Oe), the domain structure shows a sudden rotation and stripes change their orientation to ± 60° with respect to the applied field (Fig. 2b). The perpendicular stripes (Fig. 2a) and the ± 60° stripes indicate the three-fold symmetry of the (111) plane of the magnetic film.

At sufficiently high field (55 Oe), the stripe domains along the hard axis will also diminish and the film becomes a uniform domain. Fig. 2c shows how the existence of a permalloy array affects the stripe pattern. A channel of uniform domain region is created along the permalloy array. As will be seen later, efficient mode conversion occurs only when uniform domains are created.

IV. ANNIHILATION FIELD

As mentioned in I, it is desirable to operate the waveguide as a switch or a modulator in a single domain film. We have measured the in-plane magnetic field intensity (H_a) required to annihilate the stripe domains. Fig. 3 is the result of the measurement. In the figure, $\theta = 0$ refers to the easy axis and $\theta = 90$ is along the hard axis. Maximum annihilation fields of the order of 50 to 60 Oe are found along the direction $\theta \cong 0$, 60, 120 degrees. Here again the threefold symmetry of the (111) plane is revealed.

The minimum annihilation fields of the order of 1 to 3 Oe are found along the direction ± 45° from the hard axis ($\theta = 90°$). Fig. 3 implies the following:

Assuming the light propagation is along $\theta = 0$ and only a longitudinal field is applied to the same direction, it requires 60 Oe of bias field to operate the film in uniform domain condition. Such a high bias field is undesirable on two counts:

1) The uniform bias field will be too strong and override the periodic field generated by the permalloy array.

2) Even if a periodic field can be induced (for instance, with a meanderline structure), the bias field will be too strong for a small switching field to rotate the magnetization.

On the other hand, if a transverse field is also applied in addition to the longitudinal field, so that the resultant bias field is oriented along the direction where H_a is small, 45° or 135° in Fig. 3, the stripe domain will be eliminated at a much lower magnetic field

$H_a \simeq 1$ to 3 (Oe).

This is our interpretation of the reason why a transverse bias field is needed for efficient mode conversion at relatively low bias field. In essence, although the transverse field is not directly contributing to the mode conversion via Faraday rotation, its existence eliminates the stripe domain which prevented the film from performing high efficiency mode conversion.

The figure also implies that, if the light beam is propagated exactly along the direction where H_a is a minimum, then a transverse bias field is not required. In this case, a small longitudinal bias alone will cause mode conversion. This has been verified experimentally.

V. DOMAIN STRUCTURE AND MODE CONVERSION

In order to investigate directly the effect of magnetic domains on the mode conversion, we have built an experimental setup for viewing the domain structure through polarized white light and simultaneously measuring the mode conversion efficiency of a guided wave at 1.15 μ.

Fig. 4 is an example in which the permalloy array and, therefore, the light propagation is aligned along the easy axis. The conversion efficiencies are respectively (a) 0%, (b) 60%, and (c) 65%. Along this orientation, a transverse field of 4.8 Oe was applied.

Fig. 5 is the case where the permalloy array is in the direction of 45° away from the hard axis. The conversion efficiencies are respectively (a) 28%, (b) 60% and (c) 65%. In this case, no transverse field was required to obtain 65% conversion.

In either case, significant conversion efficiency is observed only when the stripe domain is eliminated along the line of light propagation.

VI. CONCLUDING REMARKS

Our investigation leads us to the following conclusions:

a) (111) plane garnet films $(Y_{2.5}Gd_{.5})(Fe_4Ga_1)O_{12}$ exhibit stripe magnetic domain patterns which can be eliminated by in-plane applied magnetic field.

b) Efficient mode conversion can be achieved only when the stripe domains are eliminated along the line of light propagation.

c) The in-plane applied magnetic field required to annihilate the stripe domains is minimum at ± 45° from the hard axis.

d) This minimum annihilation field ranges from less than 1 Oe to 3 Oe, depending on the films. Among our samples, Sample #526 shows uniform magnetic domain, even in the earth's magnetic field ($\cong$ 0.5 Oe). By rotating the Sample #526 in the earth's magnetic field, one can at most see one domain boundary dividing the whole wafer into one bright and one dark half. In such a sample, the B-H curve (Fig. 1a) also exhibits a very small saturation field of the same order of magnitude.

The Sample #851 which requires a larger saturation field, as shown in the B-H curve (Fig. 1b), exhibits stripe domains in the earth's magnetic field. The minimum annihilation field is of the order of 2.6 Oe.

e) It is our belief that for switching applications, the light beam should be propagated along the direction ± 45° from the hard axis.

In so doing, modulation by creating or eliminating the mode conversion will require a minimum applied field of the order of 0.5 Oe to 3 Oe.

f) In the generation of fast rise time modulating magnetic field, one can use a strip transmission line to create the magnetic field.

For a minimum required field of 0.5 Oe, for instance, the electric current required to generate this magnetic field will be dependent on the geometrical size of the strip line.

Since the power consumed will be the I^2R loss of this current in the terminating resistance, it is necessary to calculate the minimum current for an optimum strip line geometrical structure. We will analyze this problem in our subsequent program.

VII. FINANCIAL STATEMENT

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Required Level of Effort	Inception to Date Level of Effort
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REFERENCES

1. S.C.-C. Tseng, A. R. Reisinger, E. A. Giess and C. G. Powell, "Appl. Phys. Lett. 24, 265 (15 March, 1974)

2. P. Wolf, J. Appl. Phys. 32, 95S (March 1961)

- Figure Captions -

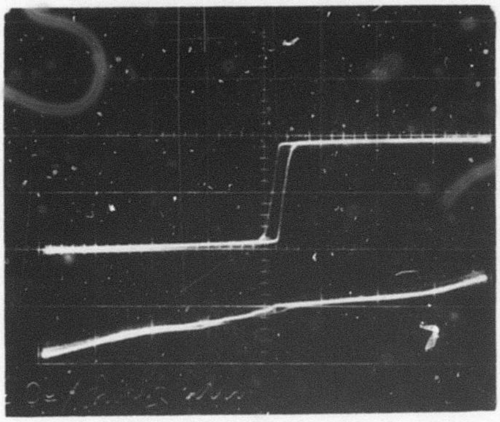
Figure 1. B-H loops with 60-Hz in-plane magnetic field. Horizontal scale is 1 Oe/cm. Upper trace is easy axis, lower trace hard axis. Sample #526 (a) has a lower coercivity than sample #851 (b).

Figure 2. Observation of domains between crossed polarizer and analyzer. Magnetic easy axis is horizontal. In the absence of magnetic field (a) the stripe pattern is perpendicular to the easy axis. Photograph (b) shows the appearance of stripes inclined at $\pm 60^\circ$ when a magnetic field is applied along the hard axis. A periodic permalloy structure (c) creates uniform regions in its vicinity.

Figure 3. Magnitude of in-plane magnetic field required to annihilate the stripe pattern vs field orientation. The data is consistent with a three-fold symmetry in the [111] plane.

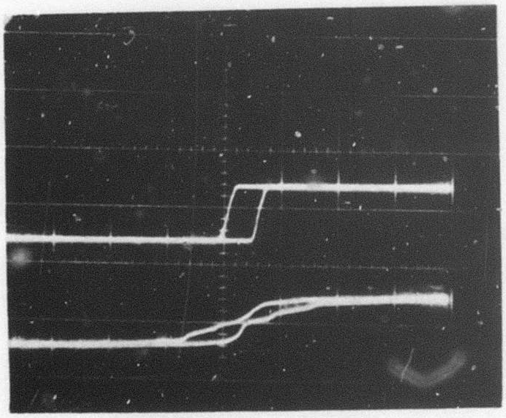
Figure 4. Correlation between conversion efficiency and domain structure. The increase in efficiency from 0 (a) to 60% (b) and 68% (c) is clearly related to the annihilation of the stripe pattern. The permalloy structure is aligned along the easy axis.

Figure 5. Same as Figure 4, but light propagates at 45° relative to the easy axis. Notice again the correlation between the increase in efficiency from 23% (a) to 63% (b) to 65% (c) and the disappearance of the domain pattern.



(a)

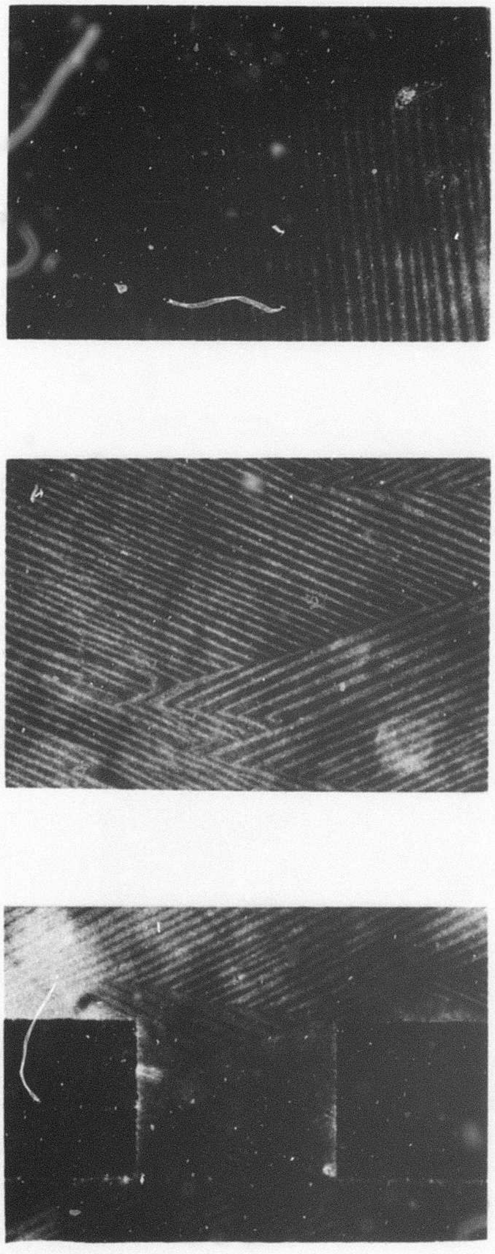
Sample #526



(b)

Sample #851

- Figure 1 -

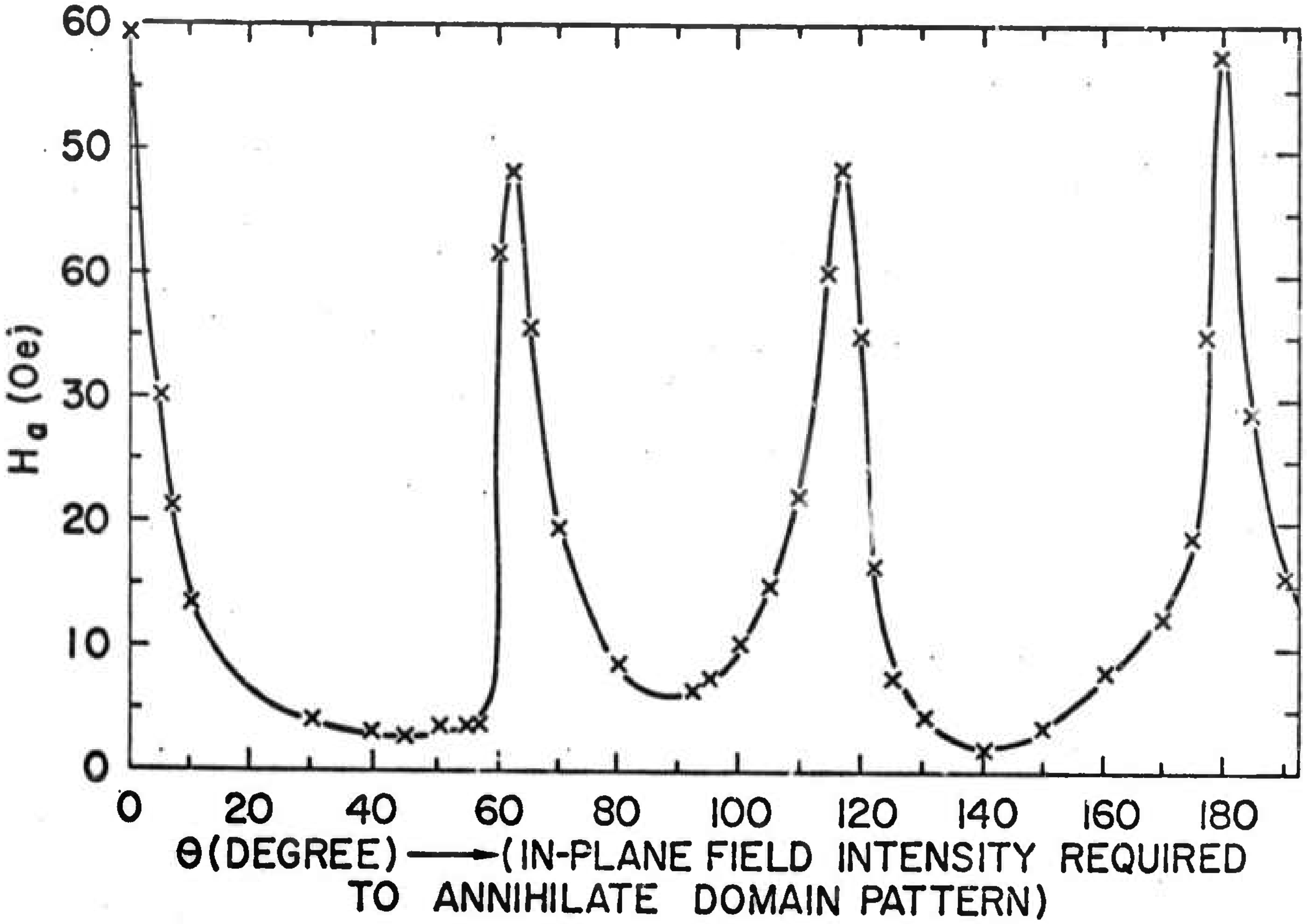


(a)

(b)

(c)

- Figure 2 -


60
50
60
30
20
10
0
H_a (Oe)
0
20
40
60
80
100
120
140
160
180
Θ(DEGREE) ——→(IN-PLANE FIELD INTENSITY REQUIRED
TO ANNIHILATE DOMAIN PATTERN)

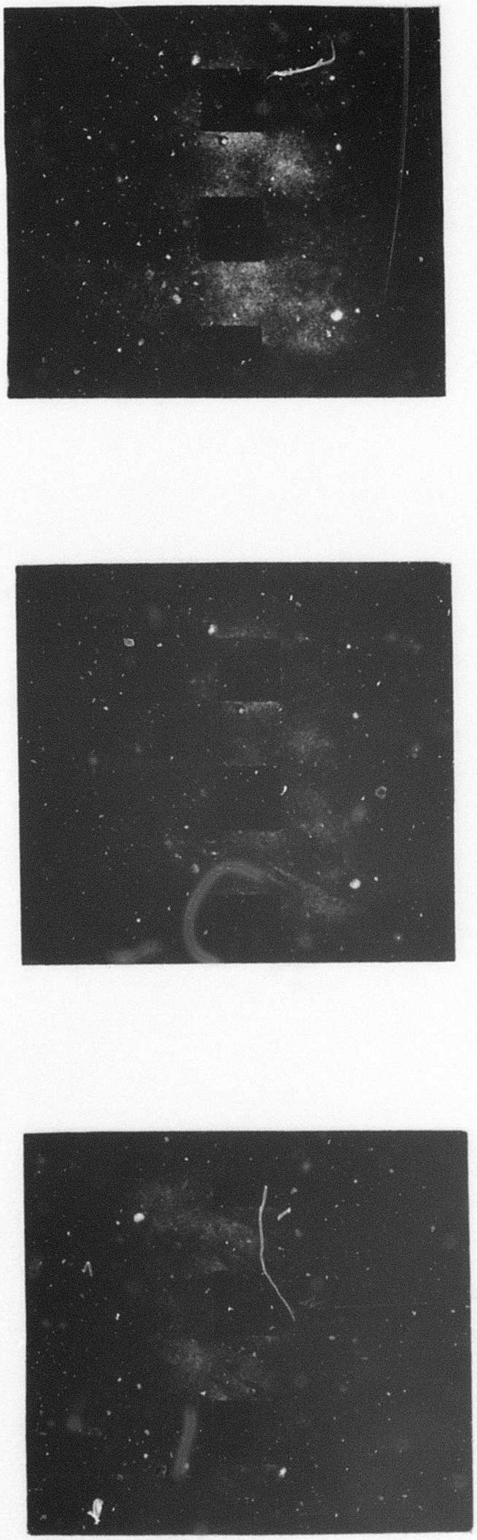
- Figure 3 -

(a)

(b)

(c)

- Figure 4 -



(a) (b) (c)

- Figure 5 -

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